§3. Evaluation of the Mechanical Properties of HTS Single-grain Bulks by Indentation

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Improvement of the mechanical properties of HTS (high-temperature superconducting) bulks is indispensable for the development of high performance HTS bulk current leads for magnetically confined fusion reactors. Investigations of the mechanical properties associated with the microstructures are informative for the improvement of the mechanical properties of HTS bulks. In this study, relationship between the mechanical properties and the microstructures of Dy123 ($DyBa_2Cu_3O_x$) bulks was investigated.

Dy123 bulk samples which had few pores were tested. These bulk samples were fabricated by Nippon Steel Corporation. The molar ratio Dy123:Dy211 (Dy_2BaCuO_5) of the precursor of these bulk samples is 100-X:X (X=15, 20 and 30). These precursors were heated in O_2 atmosphere up to 1423 K, kept at that temperature for 1 h and then cooled down to 1313 K. After that one Nd123 seed crystal was placed on the top of them in air and they were gradually cooled down. Bending test specimens with the dimensions of 2.8 x 2.1 x 24 mm^3 were cut from the bulk samples. These specimens were annealed in O_2 atmosphere at 723 K for 100 h. Three-point bending load was applied at room temperature by means of the testing machine INSTRON 4464. The fulcrum span was 21 mm and the crosshead speed was 0.1 mm/min. The longitudinal strain was measured by a 0.2 mm strain gage glued on the tensile side surface of the specimen. Side surfaces of the fractured specimens were polished. After that, Vickers indentation tests were conducted at room temperature using the hardness tester AKASHI Mvk Type C. Indentation load was 4.9 N.

The bending strength of the low porosity Dy123 bulks, which was higher than that of porous Dy123 bulks[1], increased with increase of the Dy211 content as shown in Fig. 1. It is observed that most of the Dy211 particles dispersed in the bulks have the size below 3 μm and the bulk with larger Dy211 content has smaller Dy211 particles. The degree of dispersion of the particles, which is defined as a ratio of the standard deviation to the average value of the inter-particle spacing, decreases with increase of the Dy211 content. Thus, the bulk with larger Dy211 content has uniform dispersion of the particles.

There is a scattering of the density of Dy211 particles (white part in Fig. 2) in each melt-grown bulk sample. Large Dy211 particles are observed in the area with low density of the Dy211 particles. Both the length of diagonals of the scar and the length of cracks initiated from corners of it in the area with low density of the Dy211 particles (Fig. 2 (b)) were slightly longer than those in the area with uniform dispersion of the Dy211 particles (Fig. 2 (a)). Fracture toughness was evaluated on the basis of these lengths by using the equations defined in the JIS-R-1607[2]. The Young's modulus values based on the slope of the bending stress-strain curves were used for the calculation. The fracture toughness values evaluated for the indentation scars shown in Fig. 2 (a) and (b) were about 1.55 and 1.25 MPa $m^{1/2}$, respectively. Thus, uniform dispersion of the Dy211 particles is effective in improving the mechanical properties of HTS bulks, which is consistent with the bending test results.

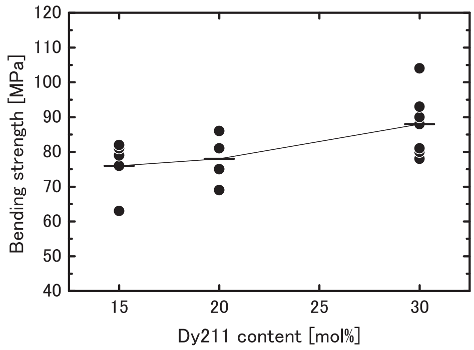
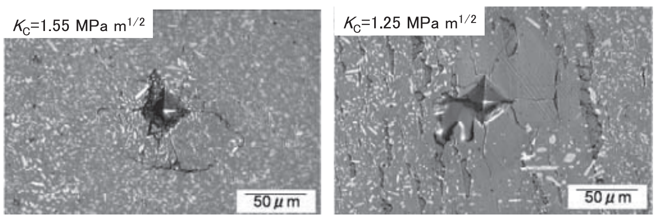


Fig. 1. Relationship between bending strength of low porosity Dy123 bulks and Dy211 content of precursor of these bulks.



(a) (b)

Fig. 2. Vickers indentation scars by indenting on the area with (a) uniform dispersion of Dy211 particles and (b) low density of Dy211 particles of low porosity Dy123 bulk fabricated from precursor with 30 mol% Dy211 powder.

1) Murakami, A. et al.: Physica C **468** (2008) 1395.
2) JIS-R-1607: testing methods for fracture toughness of fine ceramics, Japanese Industrial Standard.